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STUDY OF MICROSTRIP ANTENNAS FOR WIDEBAND AND MULTIPOLARIZATION APPLICATIONS

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The purpose of this research project is to analyze the properties of microstrip antennas in multilayered anisotropic material for wideband and multipolarization applications. The following problems are considered to be of major importance: (1) the development of the dyadic Green's function formulation; (2) the excitation of modes of multilayered microstrip antennas; (3) electromagnetically coupled microstrips in multilayer anisotropic media; (4) multi-element multi-resonance structures. Whereas the dyadic Green's function in conjunction with the method of moments provides a unified approach to all the problems, the vector transform technique can be used to solve problems with symmetry. The mode analysis on the dyadic Green's function will provide physical insight in finding a suitable design.

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The purpose of this research project is to analyze the properties of microstrip antennas in multilayered anisotropic media for wideband and multi-polarization applications. The following problems are considered to be of major importance: (1) the development of dyadic Green's function formulation; (2) the excitation of modes of multilayered microstrip antennas; (3) electromagnetically coupled microstrips in multilayer anisotropic media; (4) multi-element multi-resonance structures.

The dyadic Green's function in conjunction with the method of moments is used as a unified approach to all microstrip antenna problems. Different vector transform techniques are employed to achieve compact formulation and ease in the application of the numerical procedure. The Finite-Difference Time-Domain (FD-TD) Technique is also used to calculate the input impedance of various microstrip antenna structures with different feeding configurations. A new FD-TD grid model is developed for microstrip problems in anisotropic media. Due to the complexity of feeding networks of microstrip antennas and arrays, special attention is devoted to microstrip lines and discontinuities in multilayered media.

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Input Impedance of a Probe-Fed Stacked Circular Microstrip Antenna

Conventional microstrip antennas, consisting of a single perfectly conducting patch on a grounded dielectric substrate, have received much attention in recent years due to their many advantages, including low profile, light weight, and easy integration with printed circuits. However, due to their resonant behavior their use is severely limited in that they radiate efficiently only over a narrow band of frequencies, with bandwidths typically only a few percent. While maintaining the advantages of conventional single patch microstrip antennas, microstrip antennas of stacked configurations, consisting of one or more conducting patches parasitically coupled to a driven patch, overcome the inherent narrow bandwidth limitation by introducing additional resonances in the frequency range of operation, achieving bandwidths up to 10-20 percent. In addition, stacked microstrip configurations have achieved higher gains and offer dual frequency operation.

The first multilayered microstrip element was described by Oltman as an electromagnetically coupled microstrip dipole where a printed dipole was excited by an open-ended microstrip transmission line in the same plane as the dipole or in the layer below the dipole. Hall et al. stacked rectangular microstrip patches in two- and three-layer configurations, achieving bandwidths in excess of 16 times that of alumina substrate microstrip antennas, and noted that the stacked configurations allowed for simple antenna/circuit integration. Experimental work by others with two-layer stacked circular and rectangular microstrip patches produced wider bandwidths and higher efficiencies than those obtained with conventional single patch configurations. Stacking microstrip patches for dual frequency use was investigated experimentally for circular disks by Long et al. and for annular rings by Dahele et al.

While the experimental work has been abundant, the theoretical work is limited. The open structure of the stacked microstrip antenna configuration has been analyzed to study the resonant frequencies, modes, and radiation patterns. Using the Hankel transform, a numerical analysis of a circular microstrip disk antenna with a parasitic element is presented. The resonant frequencies of the stacked microstrip disks have been rigorously calculated and related to the constitutive resonances of the stacked configuration. The method of moments with triangular basis functions was employed to analyze the open structure of a two-layer circular microstrip antenna excited by an incident plane wave. A spectral domain iterative analysis of single- and double-layered microstrip antennas using the conjugate gradient algorithm to compute radiation patterns was described. In particular, there is little or no theoretical analysis of the input impedance of coaxial probe-fed stacked microstrip patches. However, the input impedance for conventional single-layer coaxial probe-fed microstrip antennas of circular, rectangular, annular ring, and elliptic geometries has been investigated by many authors. The impedance parameters of two planar coupled microstrip patches have also been studied.

In the calculation of the input impedance of probe driven microstrip antennas on thin substrates, the effect of the probe results in an additional inductive component to the input impedance. This probe inductance has been accounted for by several authors through use of a simple formula. In more rigorous methods to include the effects of the probe, an "attachment mode" in the disk current expansion is used to account for the singular behavior of the disk current in the vicinity of the probe, ensure continuity of the current at the probe/disk junction, and speed up the convergence of the solution. An "attachment mode" which represented the disk current of a lossy magnetic cavity driven by a uniform cylindrical probe current was introduced. More recently, a similar "attachment mode" has been applied. Other "attachment modes," with the $1/\rho$ dependence in the vicinity of the probe and the appropriate boundary condition on normal current, defined over the entire disk or locally over a portion of the disk, have also been used. The problem of center-fed microstrip disk was investigated including both "attachment mode" and edge current terms. In a different approach, the effects of the probe were accounted for by expanding the currents on the disk and probe in terms of the modes of a cylindrical magnetic cavity satisfying boundary conditions on the eccentrically located probe. Radiation losses were accounted for by an effective loss tangent and fringing fields by an effective disk radius.

Considered here is a microstrip antenna consisting of two circular microstrip disks in a stacked configuration driven by coaxial probe excitation.[1,11,30] The two different stacked configurations are investigated. A rigorous analysis of the two stacked circular disks in a layered medium is performed using a dyadic Green's function formulation. Using the vector Hankel transform, the mixed boundary value problem is reduced to a set of coupled vector integral equations and solved by employing Galerkin's method in the spectral domain. The current distribution on each disk is expanded in terms of two sets of basis functions. The first set of basis functions used are the complete set of transverse magnetic (TM) and transverse electric (TE) modes of a cylindrical resonant cavity with magnetic side walls. The second set of basis functions used employ Chebyshev polynomials and enforce the current edge condition. An additional term in the current expansion is taken to account for the singular nature of the current on the disk in the vicinity of the probe and to ensure continuity of current at the junction. This term, the "attachment mode," is taken to be the disk current of magnetic cavity under a uniform cylindrical current excitation. It is shown here explicitly that continuity of the current at the probe/disk junction must be enforced to rigorously include the probe self-impedance. The convergence of the results is investigated and ensured by using a proper number of basis functions. The input impedance of the stacked microstrip antenna is calculated for different configurations of substrate parameters and disk radii. Disk current distributions and radiation patterns are also presented. Finally, the results are compared with experimental data and shown to be in good agreement.

Impedance Parameters and Radiation Pattern of Cylindrical-Rectangular and Wraparound Microstrip Antennas

Cylindrical microstrip antennas find many applications pertaining to high speed aircrafts and space vehicles, because of their conformity with the aerodynamical structure of such vehicles. Recently there has been some progress in the theoretical study of such antennas, where the radiation from various cylindrical microstrip elements was computed by assuming an electric surface current distribution on the microstrip patch. The excitation problem of realizing such a current distribution still need to be addressed. Furthermore, the input impedance for the cylindrical microstrip antennas has not been reported.

In our work, the more realistic problem of the radiation from a cylindrical microstrip antenna excited by a probe is investigated.[2] Both the cylindrical-rectangular and the wraparound elements are discussed. The current distribution on the patch is rigorously formulated using a cylindrically stratified medium approach. A set of vector integral equations which governs the current distribution on the patch are derived. This set of equations is then solved using Galerkin's method in which the patch current is expanded in terms of a complete set of basis functions that can take into account the edge singularity condition. The input impedance together with the radiation pattern are derived both exactly and in the small substrate thickness limit where a single mode approximation is employed. For thick substrates, hybrid modes are excited, and only in the case of axially symmetric modes ($n = 0$) the TE_{0m} is decoupled from the TM_{0m}, and modes of different parity do not couple. The presence of the dielectric substrate widens the bandwidth and broadens the radiation pattern. The radiation pattern is insensitive to the substrate thickness (especially for high dielectrics). For wraparound antenna, all current modes with no axial variation tend to weakly radiate and consequently have narrow bandwidth. When the TE_{01} mode is excited, the wraparound antenna works as a good antenna. The rectangular-cylindrical patch is, generally, less radiating than the wraparound.

Resonant Frequencies of Stacked Circular Microstrip Antennas

Conventional microstrip antennas consisting of a single perfectly conducting patch on a grounded dielectric slab, have received much attention in recent years due to their many advantages, including low profile and light weight. However, due to their resonant behavior, their use is severely limited in that they radiate efficiently only over a narrow band of frequencies, with bandwidths typically only a few percent. Techniques for increasing the bandwidth have included stacking a number of microstrip patches in multilayer configurations, introducing additional resonances in the frequency range of interest and achieving wider bandwidths.

In particular, considered here is a microstrip antenna consisting of two microstrip disks in a stacked configuration.[3] Using the dyadic Green's function formulation, a rigorous analysis of the two stacked circular microstrip disks in a layered medium is performed. A set of coupled integral equations for the current distribution on the disks is derived using the vector Hankel transform. This coupled set is then solved using Galerkin's method. The choice of the current basis functions is based on the currents of the magnetic wall cavity. Complex resonant frequencies are calculated as a function of the layered substrate, permittivities and thicknesses, and the ratio of the two disks radii. The resonant frequencies of two different stacked configurations are studied as function of the coupling interaction. Critical coupling between the two resonators occurs at the point where the real part of the resonance curves for the two isolated resonators intersect. The splitting of the complex resonance curves at this point is a function of the strength of the coupling between the two resonators. The dual frequency or wide band operation is shown to be achieved by changing the coupling coefficient.

Resonance in Cylindrical - Rectangular and Wraparound Microstrip Structures

Cylindrical microstrip structures are important in many applications where they can be flush-mounted on curved surfaces such as space vehicles, missiles, and boosters. The microstrip antenna elements that are commonly used on these surfaces are of either the wraparound or the cylindrical-rectangular type.

The resonance frequencies of microstrip patches placed on planar structures have been studied extensively. On the other hand, the study of microstrip antennas placed on curved surfaces has attracted less attention. The resonance frequencies of a cylindrical-rectangular microstrip patch were calculated using magnetic-wall cavity model, thus ignoring the fringing field effects and radiation loss. In such an analysis, the resonance frequencies are pure real, thus limiting the validity of the obtained results.

In this work, a rigorous analysis of the resonant frequency problem of both the cylindrical- rectangular and the wraparound microstrip structures is presented using two different approaches: integral equation formulation and a perturbational approach.[4,29] Using Galerkin's method in solving the integral equations, the complex frequencies are studied with sinusoidal basis functions. The effect of the edge singularity of the patch current on the convergence is investigated. Numerical results show that the HE_{10} mode for the wraparound and the cylindrical-rectangular patches have narrow bandwidth and thus, they are more appropriate for resonator applications. The TE_{01} and HE_{01} modes of the wraparound and cylindrical-rectangular patches, respectively, have wide bandwidth and they are efficient radiating modes.

Propagation Properties of Striplines Periodically Loaded with Crossing Strips

Since the feeding networks of microstrip antennas and arrays in multilayered media are becoming more complicated, a problem of practical interest is the study of propagation characteristics of a microstrip line in the presence of crossing strips.

The analysis of striplines and finlines with periodic stubs has been studied by Kitazawa and Mittra, where a technique based on the network-analytical formulation is used. A slow-wave coplanar waveguide on periodically doped semiconductor substrate has been carried out by Fukuoka and Itoh. Gu and Kong used a quasi-static approach to study single and coupled lines with capacitively loaded junctions. The propagation characteristics of signal lines in a mesh plane environment has been presented by Rubin. More recently, the propagation characteristics of signal lines in the presence of periodically perforated ground plane was studied by Chan and Mittra.

In this work, the dispersion characteristics of strip lines crossed by metallic strips and embedded in the same isotropic layer and bounded by two conducting planes, is investigated.[5] A rigorous dyadic Green's function formulation in the spectral domain is used and a set of coupled vector integral equations for the current distribution on the conductors is derived. Galerkin's method is then applied to derive the matrix eigenvalue equation for the propagation constant. The dispersion properties of the signal lines are studied for both cases of finite and infinite length crossing strips.

The effects of the structure dimensions on the passband and stopband characteristics are investigated. For crossing strips of finite length, the stopband is mainly affected by the period, the crossing strip length, and the separation between the signal and the crossing strips. For crossing strips of infinite length carrying travelling waves, attenuation along the signal line exists over the whole frequency range of operation.

Integral Equation Solution to the Guidance and Leakage Properties of Coupled Dielectric Strip Waveguides

The leakage phenomenon is important in the area of millimeter-wave integrated circuits and integrated optics. Theoretical analyses and experiments have been performed to investigate this phenomenon. The leakage is due to the TE-TM coupling occurring at the geometrical discontinuities, and the leaky power in the form of a surface wave propagates in the background medium. The leakage loss can be larger than the dielectric loss for some low-loss materials and may cause crosstalk to neighboring circuit components. On the other hand, the leakage properties can be deliberately utilized in designing directional couplers.

There are several methods used to analyze dielectric strip waveguides. The approximate field matching method is used to analyze the rectangular dielectric waveguide. This method considers only the fields in the regions attached to the four sides of the guide cross section, and the fields in the other regions are assumed negligible . The transverse propagation constants are determined by solving the corresponding slab waveguide problems in two transverse directions of the guide cross section separately. This method is an approximate one, and can only predict the real part of the propagation constant.

The effective dielectric constant (EDC) method has been used to solve for the dispersion relations of dielectric strip waveguides consisting of more than two constituent regions in the cross section. This method is applied when the width of each constituent region is large compared with the thickness of the guiding layers, and the difference of the effective dielectric constants between different constituent regions is small. However, the EDC method neglects the geometrical discontinuities across the interfaces between constituent regions and cannot be used to predict the imaginary part of the propagation constant; thus the leakage is not considered.

The mode-matching technique has been used to solve for the propagation constant of dielectric strip waveguides. Using this method, the leakage properties of the guiding structure has been investigated. This technique can be applied to guiding structures in which the modes of the constituent regions can be determined. However, it cannot be applied when the cross section of the guiding structure is of arbitrary shape or has inhomogeneous dielectric constant. The finite element method, and the finite difference method have been used to solve for the dispersion characteristics of the dielectric waveguides. However, the leakage effect was not investigated. The integral equation method has been used to solve for the dispersion relation of the rectangular dielectric waveguide. This method incorporates the continuous spectrum, and hence the radiation loss is taken into account. However, no results concerning practical single and coupled dielectric strip waveguides were presented, and the leakage properties are investigated.

In this work, an integral equation formulation using the dyadic Green's function is derived to solve for the dispersion relation of single and coupled dielectric strip waveguides.[6,31] A method to predict the leakage is presented, and the leakage properties are investigated. The integral equation formulation for an arbitrary number of inhomogeneous dielectric strips is derived and Galerkin's method is used to obtain the matrix eigenvalue equations. Numerical results and discussions are presented.

The Propagation Characteristics of Signal Lines with Crossing Strips in Multilayered Anisotropic Media

In high performance compact modules, signal transmission lines between integrated circuit chips are embedded in multilayered dielectric medium. These signal lines are usually placed in different layers and run perpendicular to each other. The interaction between the orthogonal crossing lines and the signal line affects its propagation characteristics and may cause considerable signal distortion.

The interaction of a pair of crossing lines in isotropic medium has been studied using a time-domain approach, where coupling is described qualitatively. This method becomes computationally expensive when the number of crossing lines increases. With many identical crossing strips uniformly distributed above the signal line, the transmission properties are characterized by stopbands due to the periodicity of the structure. Periodic structures have been investigated using frequency-domain methods. Periodically nonuniform microstrip lines in an enclosure are analyzed on the basis of a numerical field calculation. A technique based on the network-analytical formalism of electromagnetic fields has been used to analyze striplines and finlines with periodic stubs. The propagation characteristics of waves along a periodic array of parallel signal lines in a multilayered isotropic structure in the presence of a periodically perforated ground plane and that in a mesh-plane environment have been studied. More recently, the effect of the geometrical properties on the propagation characteristics of strip lines with periodic crossing strips embedded in a shielded one-layer isotropic medium have been investigated.

In this work, both open and closed multilayered uniaxially anisotropic structures are considered.[7,28] A full-wave analysis is used to study the propagation characteristics of a microstrip line in the presence of crossing strips. The signal line and the crossing strips are assumed to be located in two arbitrary layers of a stratified uniaxially anisotropic medium. An integral equation formulation using dyadic Green's functions in the periodically loaded structure is derived. Galerkin's method is then used to obtain the eigenvalue equation for the propagation constant. The effects of anisotropy on the stopband properties are investigated. Numerical results for open and shielded three-layer uniaxially anisotropic media are presented.

A Hybrid Method for the Calculation of Resistance and Inductance of Transmission Lines with Arbitrary Cross Section

With the ever increasing speed and density of modern integrated circuits, the need for electromagnetic wave analysis of phenomena such as the propagation of transient signals, especially the distortion of signal pulses, becomes crucial. One of the most important causes of pulse distortion is the frequency dependence of conductor loss, which is caused by the "skin effect", and which can be incorporated into the circuit models for transmission lines as frequency-dependent resistance and inductance per unit length. Efficient and accurate algorithms for calculating these parameters are increasingly important.

In this work, a new hybrid cross-section finite element/coupled integral equation method is presented, which is both efficient and flexible in regards to the kinds of configurations which can be handled.[8] The technique is a combination of a cross-section finite element method, which is best for high frequencies. An interpolation between the results of these two methods gives very good results over the entire frequency range, even when few basis functions are used.

For low frequencies, we use a cross-section finite element method. Our method is based on the Weeks method, but with two major modifications. First, we use triangular patches, rather than the rectangular patched used by Weeks; secondly, we do not change the distribution of patches with frequency. It is shown that both of these improvements, along with the fact that we do not use the cross-section method for high frequencies, greatly increase the efficiency of the method.

For high frequencies, we use a coupled surface integral equation technique. Under the quasi-TEM assumption, the frequency-dependent resistance and inductance result from the power dissipation and magnetic stored energy, which can be calculated by solving a magnetoquasistatic problem, with the vector potential satisfying Laplace's equation in the region outside all the conductors. The resistance and inductance are usually given by integrals of these field quantities over the cross-sections of the wires, but by using some vector identities it is possible to convert these expressions to integrals only over the surfaces of the wires. These expressions contain only the current at the surface of each conductor, the derivative of that current normal to the surface, and constants of the vector potential. A set of coupled integral equations is then derived to relate these quantities through Laplace's equation and its Green's function outside the conductors and the diffusion equation and its Green's function inside the conductors. The method of moments with pulse basis functions is used to solve the integral equations. This method differs from previous work in that the calculation of resistance and inductance is based on power dissipation and stored magnetic energy, rather than on impedance ratios. It will therefore be more easily extended to structures where non-TEM propagation can occur.

For the intermediate frequency range, where the conductors are on the order of the skin depth, we found it very efficient to interpolate between the results of the cross-section and surface methods. The interpolation function was based on the average size of the conductors, measured in skin depths, and was of the form $1/(1+0.16a^2/\delta^4)$, where a is the average cross-section of the conductors, and δ is the skin depth.

Transient Analysis of Frequency-Dependent Complex Systems with Nonlinear Terminations

Most of microwave and digital integrated circuits are terminated with semiconductor devices, such as diodes and transistors, having nonlinear input impedances. With sufficient high magnitude of signals the terminal loading condition of the circuit will vary with the amplitude of transmitted signals. The nonlinear effects of the terminal load should then be taken into account. Two commonly-used methods to deal with this kind of nonlinear problems are the direct time domain approach and the combination of time domain treatment with frequency analysis, such as the harmonic balance and the modified harmonic balance techniques.

As the speeds of integrated circuits and the operating frequency range of microwave circuits increase, the frequency-dependent effects can no longer be neglected. In this case, the problem becomes more complicated, and the approaches mentioned above cannot be readily applied. The direct time domain approach is inapplicable to frequency-dependent systems. The harmonic balance and modified harmonic balance techniques have the common deficiency that they are inefficient in treating a nonlinear system supporting signals having very wide frequency bandwidths, such as narrow pulses of less than one nanosecond in duration.

A nonlinear analysis in the time domain using impulse responses from a frequency domain analysis based on the admittance matrix has been presented. The principle of this method is to first obtain the impulse responses through analyzing the linear portion of the investigated system in the frequency domain, and then using the impulse responses to solve the entire nonlinear problem in the time domain. This method has been improved through artificially introducing quasi-matched passive networks. This method can be applied to frequency dependent transmission line problems with nonlinear loads. Modified approaches have been developed by using the concept of wave transmission and reflection instead of voltage and current. These modified methods overcome the necessity of using artificial quasi-matched networks. However, only a single transmission line or a two port system has been discussed.

In this work, a generalization of the modified method is presented to analyze arbitrary multi-port systems containing frequency dependent elements as filters, discontinuities, and loads containing nonlinear resistances and capacitances.[9] The method is applied to analyze a pair of coupled dispersive transmission lines partly terminated in nonlinear load, and discontinuity effects of uncompensated and compensated right angle microstrip corners. Finally, the transient response of a microwave switcher is presented.

Application of the Three Dimensional Finite Difference Time Domain Method to the Analysis of Planar Microstrip Circuits

Frequency domain analytical work with complicated microstrip circuits has generally been done using planar circuit concepts in which the substrate is assumed to be thin enough that propagation can be considered in two dimensions by surrounding the microstrip with magnetic walls. Fringing fields are accounted for by using either static or dynamic effective dimensions and permittivities. Limitations of these methods are that fringing, coupling, and radiation must all be handled empirically since they are not allowed for in the model. Also, the accuracy is questionable when the substrate becomes thick relative to the width of the microstrip. To fully account for these effects, it is necessary to use a full-wave solution.

Full-wave frequency domain methods have been used to solve some of the simpler discontinuity problems. However, these methods are difficult to apply to a typical printed microstrip circuit.

Finite difference time domain methods have recently been used to effectively calculate the frequency dependent characteristics of microstrip discontinuities. Analysis of the fundamental discontinuities is of great importance since more complicated circuits can be realized by interconnecting microstrip lines with these discontinuities and using transmission line and network theory. Some circuits, however, such as patch antennas, may not be realized in this way. Additionally, if the discontinuities are too close to each other the use of network concepts will not be accurate due to the interaction of evanescent waves. To accurately analyze these types of structures it is necessary to simulate the entire structure in one computation. The finite difference time domain (FDTD) method shows great promise in its flexibility to handle a variety of circuit configurations. An additional benefit of the time domain analysis is that a broadband pulse may be used as the excitation and the frequency domain parameters may be calculated over the entire frequency range of interest by Fourier Transform of the transient results.

In this work, the frequency dependent scattering parameters have been calculated for several printed microstrip circuits, specifically, a line-fed rectangular patch antenna, a low pass filter, and a rectangular branch line coupler.[10,32] These circuits represent resonant microstrip structures on an open substrate, hence, radiation effects can be significant, especially for the microstrip antenna. Calculated results are presented and compared with experimental measurements.

The FDTD method has been chosen over the other discrete methods (TLM or Bergeron's) because it is extremely efficient, its implementation is quite straightforward, and it may be derived directly from Maxwell's equations. Many of the techniques used to implement this method have been demonstrated previously, however, simplification of the method has been achieved by using a simpler absorbing boundary condition. This simpler absorbing boundary condition yields good results for the broad class of microstrip circuits considered by this paper. Additionally, the source treatment has been enhanced to reduce the source effects.

Analysis of Diffraction from Chiral Gratings

There has been considerable interest in the theoretical study of scattering from chiral media. Chiral medium characterized by biisotropic constitutive relation is a special case of the bianisotropic medium whose electromagnetic properties has been extensively studied by Kong.

Periodic gratings have been the object of extensive research through the years because of its many applications in distributed feedback laser, integrated optics, acousto-optics, quantum electronics, and holography. For the analysis of wave diffraction by periodic surface grating, methods including the method of moments and extended boundary condition method are rigorous and in general computationally efficient. For the analysis of periodic slanted dielectric gratings, a coupled-wave method has been developed.

In this work, the coupled-wave theory is generalized to analyze the diffraction of waves by chiral gratings for arbitrary angle of incidence and polarizations.[12] Numerical results are illustrated for the Stokes parameters of diffracted Floquet modes versus the thickness of chiral gratings with various chiralities. Both horizontal and vertical incidences are considered for illustration. The diffracted waves from chiral gratings are in general elliptically polarized; and at some particular instances, it is possible for chiral gratings to convert a linearly polarized incident field into two nearly circularly polarized Floquet modes propagating in different directions.

Quasistatic Fields Due to an Electrode Mounted on a Conducting Pad of Finite Extent in a Planar Stratified Medium

In geophysical prospection for oil, a borehole is drilled in the earth. The borehole is filled with mud to balance the downhole pressure. The conductivity of the mud is usually higher than the conductivity of the surrounding rock formation. The mud may flush into the rock formation, generating an invaded zone behind the borehole wall. Usually the conductivity of the invaded zone forms a profile with conductivity values varying between that of the mud and the rock formation.

In this work, we will consider a canonical problem that can be employed to study the physics of electrode tools that are routinely used in prospecting the conductivity of rock formations.[13] A perfectly conducting electrode is mounted on a metallic pad of a finite extent. The pad is assumed to be perfectly conducting and has the effect of focusing the current into the formation. The pad-electrode arrangement is pressed against the borehole wall, injecting low-frequency currents into the rock formation.

To simplify the analysis, the geophysical environment is modeled as a planar stratified lossy medium. The pad is modeled as a perfectly conducting rectangular plate, and the electrode is modeled as a small rectangular patch located in the center of a hole on the pad surface and is isolated from the pad by an insulator. The pad is embedded in a planar stratified medium of an arbitrary number of layers. An electrostatic formulation in the spectral domain is introduced starting from a transverse magnetic (TM) wave formulation. An integral equation in the current is then obtained by imposing the appropriate boundary condition on the pad-electrode surface. Expressions for the potential distribution in each layer are also derived. The method of moments is applied to solve the integral equation numerically. Finally, the numerical results are presented and discussed to investigate the performance of the pad-electrode as a geophysical tool. Different models representing the measurement environment are investigated. Four different types of conductivity profiles for the invaded zone are also considered.

Response of Layered Media to Current Sources with Arbitrary Time Behavior

The transient fields of a line current source on a layered medium are calculated using the double deformation technique, in which complex integrals are deformed in the transverse wavenumber and frequency planes. Singularities from these complex planes correspond to physical modes of the structure, such as guided and leaky waves, and the relative importance of each to the overall response can be discovered. Unlike the Cagniard-deHoop method, double deformation can be applied to dispersive and dissipative media. Also, the causality of the electromagnetic signal can be shown analytically.

In this work, a modification to the double deformation technique is presented, which consists of splitting the Fourier transform of the source current into two halves, one for times before the arrival at the observation point, and one after.[14] This greatly increases the range of sources to which the double deformation technique can be applied. Another advantage of the modification, the individual causality and continuity of each mode, will be shown. The relative importance of the different wave modes will be demonstrated, as well as the improvement of this method over more brute-force approaches. Results are shown both for line and strip currents on the surface of a coated perfect conductor, for cases where the dielectric coating is both lossless and dissipative. In most cases, only a small number of modes suffices to reproduce the important features of the response, including the arrivals of reflected and lateral rays. The importance of each type of arrival depends on certain features of the time function, especially the initial slope. The response due to a strip current resembles that of a line current, with some smoothing of the sharper features. Then, the modified double deformation technique is generalized to the more complicated configurations of vertical electric dipole (VED) and vertical magnetic dipole (VMD) sources. A physical interpretation of the contributing factors are attempted and the solution methodology is extended to include lossy media.

Probe Excitation of a Center-Fed Circular Microstrip Antenna Employing the Weber Transform

The analysis of microstrip antennas with electrically thick substrates find many applications pertaining to millimeter wave systems and in achieving wide bandwidth. The approximation to the probe feed where it is replaced by a uniform current ribbon of equivalent dimensions fails to give sufficiently accurate results for the input impedance of the probe especially for thick substrates. Recently there has been some progress in this area where they solved the current distribution on the metallic probe in a closed magnetic wall cavity. They accounted for the radiation losses by lumping it artificially into an effective loss tangent.

In this work, we rigorously analyze the radiation problem of a circular patch which is center fed by a coaxial-line driven probe over a ground plane in an arbitrary layered medium.[15] We formulate the problem in terms of a scalar Weber transform which allows one to develop the Green's function of the layered medium with the probe and the microstrip patch as part of the medium. Using the scalar Weber transform, automatically enforces the boundary conditions on the probe and the patch. This allows one to cast the problem as the solution of a set of two coupled integral equations governing the tangential component of the electric field across the aperture of the coaxial line feed and that across the interface where the patch lies. This set is then solved using the method of moments. The current distribution on both the probe and the patch is then computed from the component of the magnetic field tangential to their surfaces. Furthermore, from the computed electric field across the aperture of the coaxial line feed, one obtains the reflection coefficient for the TEM mode which allows one to compute the input impedance across the terminals of the probe. The probe current distribution, input impedance and radiation pattern are computed and the obtained results are compared with those using an independent approach.

Input Impedance of a Circular Microstrip Antenna Fed by an Eccentric Probe

Most of the published work on the input impedance and other parameters of a probe-fed microstrip antenna employ an approximation to the probe feed by assuming thin dielectric substrates where the probe current can be modeled by an idealized uniform current ribbon of the same dimensions as the probe. To ensure the proper variation of the patch current near the probe and to enforce the continuity of current at the probe-patch junction, an attachment current mode has been incorporated in the patch current expansion. This leads to acceptable numerical results for the computation of the radiation pattern by the patch and for the mutual impedance between the probe and the patch. However, this approximation is not sufficiently accurate to solve for the current distribution on the patch nor for the computation of the self impedance at the terminals of the probe. Furthermore, in millimeter wave applications and for wideband operation where thick substrates or stacked structures are used, the thin substrate approximation is not valid. Recently an alternative approach for the computation of the input impedance was developed where an approximate solution satisfying the boundary condition on the metallic probe was obtained in the framework of the magnetic cavity model. The fringing of the field at the edges of the patch and the radiation and surface wave losses were artificially considered by using an edge extension formula and an effective loss tangent.

In this work, we rigorously analyze the problem of a circular microstrip disk on a thick dielectric substrate, fed by an eccentric probe.[16] The problem is formulated in terms of a Vector Weber Transform which allows one to develop the Green's function of the layered medium with the eccentric probe and the microstrip patch as part of the medium. Using the Vector Weber Transform automatically enforces the boundary conditions on the probe and the patch. This allows one to cast the problem as the solution of a set of two coupled vector integral equations governing the tangential components of the electric field across the aperture of the coaxial line feed and those across the interface where the patch lies. This set is then solved using the method of moments where the magnetic frill current across the aperture of the coaxial line is represented by a Vector Weber Series expansion. From the computed electric field across the aperture of the coaxial line feed, the reflection coefficient for the TEM mode is obtained which allows one to compute the input impedance at the terminals of the probe.

Probe Excitation of a Center-Fed Circular Microstrip Antenna Employing a Stratified Medium Formulation

Extensive work has been published on radiation by a microstrip patch excited by a probe. Most of the published work did not rigorously model the correct current distribution on the probe. In the case of electrically thin substrates, the probe current is usually approximated as being uniform along the probe. This leads to acceptable numerical results for the computation of the radiation pattern by the patch and for the mutual impedance between the probe and the patch. However, this approximation is not sufficiently accurate to solve for the current distribution on the patch nor for the computation of the self impedance across the terminals of the probe. Furthermore, this approximation is not appropriate in the case of electrically thick substrates.

In this work, we rigorously analyze the radiation problem of a circular patch which is center fed by a coaxial-line driven probe over a ground plane and situated in an arbitrary layered medium.[16] The current distribution on both the patch and the probe is rigorously formulated using a planar stratified medium approach. A set of three coupled integral equations is derived which governs the axial current distribution on the probe, the radial current distribution on the patch and the azimuthal magnetic current sheet across the aperture of the driving coaxial line. This set of equations is then solved using the method of moments. The resulting matrix equation is obtained in terms of Sommerfeld-type integrals that take into account the effect of the layered medium. These integrals are efficiently computed by a simple deformation in the complex wavenumber domain. The probe current distribution, input impedance and radiation pattern are presented and compared to the case of a uniform probe current distribution.

Transient Response of Sources Over Layered Media Using the Double Deformation Method

The transient response to electromagnetic sources over a planar, layered medium is evaluated using the double deformation method.[18] The methodology consists of deformation of the Sommerfeld and Laplace integration contours to paths of steepest descent in the complex wavenumber and frequency planes, respectively. The time-domain field solutions are then comprised of pole contributions in both the wavenumber and frequency planes and a double integration over steepest descent paths in both planes. In this approach, causality is demonstrated analytically in an elegant manner. Given that the singularities may be accurately determined, the various partial solutions appear susceptible to physical interpretation and the methodology is applicable to dispersive conditions. This is illustrated by examples. The transient response due to vertical electric (VED) and vertical magnetic dipole (VMD) sources are presented. A physical interpretation of the contributing factors are attempted and the solution methodology extended to include lossy media.

Analysis of Microstrip Discontinuities on Anisotropic Substrates

Microstrip discontinuities, such as open end, gap and step in width, have been widely studied by many authors. There are different methods for analyzing microstrip discontinuities, such as quasi-static approach, planar waveguide model and integral equation formulation. As the frequency gets higher, the quasi-static assumption is not valid. In the planar waveguide model analyses, the thickness of the substrate is assumed much smaller than the wavelength so that a two-dimensional model may be applied. In this case, the effect of the radiation and the surface waves are not considered. The integral equation method has been applied to study the open end and gap discontinuities on isotropic substrates. In applying the integral equation method, various approximations were introduced in the computation procedure. More recently, finite element expansion currents are used to formulate a full-wave analysis of microstrip discontinuities on isotropic substrates.

In this work, the open end, gap and step in width discontinuities placed on anisotro -pic substrates are rigorously analyzed.[19] Both uniaxial and tilted uniaxial anisotropy are considered. The materials are assumed to be lossless and the metal strips to be infinitely thin. A dyadic Green's function for layered anisotropic media is used to formulate a set of vector integral equations for the current distribution. The fundamental hybrid mode is assumed to be propagating on the input and output of microstrip lines. In solving the set of vector integral equations, the method of moment is employed. The basis functions for the current on the metal strip consider the edge effect. Both longitudinal and transverse currents are considered in the calculation. The propagation constant for the infinitely long uniform microstrip line is first calculated. Then the propagation constant of the fundamental mode is used to formulate the excitation of the discontinuity problem. At the discontinuity, local basis functions are used to simulate the local currents near the discontinuity. The scattering matrix is obtained, and an equivalent circuit model is proposed. The effect of the anisotropy is investigated and the results are discussed.

Finite Difference Time Domain Techniques for Two Dimensional Triangular Grids

A finite difference time domain technique for two dimensional time domain scattering of electromagnetic waves is presented in this work.[20] The triangular grids and the control region approximation are employed to discretize Maxwell's equations. The finite difference time domain techniques with uniform rectangular grids has been used in the past. The scatterers are modeled using staircases and, recently, the accuracy of this approximation has been further investigated. Several types of other grids have been proposed to improve the staircase approximation. Generalized nonorthogonal grid can model scatterer without staircasing. It has been applied to spherical systems, yet they appear to be cumbersome for general scatterers. The "distorted rectangular grid" model approximates the computational domain using rectangular grids and distorts the boundary grids to fit the interfaces. The triangular grid is used in this work, which is very flexible in dealing with arbitrary scatterers and absorbing boundaries.

The control region approximation, which calls for Delaunay and Dirichlet tessellation, has been successfully applied to the frequency domain problems in the past. Two double integral terms are obtained by integrating the Helmholtz equation about the Delaunay tessellation. The term involving the Laplace operator can be converted to a closed loop integral of normal derivatives, which can easily be approximated in finite difference manner by utilizing the orthogonal property of Delaunay and Dirichlet tessellation. The remaining term can be approximated by multiplying the field at the node with the area. In the time domain problem, the same approximation is applied to the wave equation, except the term involving time derivatives is used in time marching scheme. Alternatively, as in Yee's algorithm, the first order Maxwell's equations are solved by spatially and temporally separating the electric and magnetic fields. In the case of electric polarization, the electric fields are placed at the nodes and the magnetic fields are placed at the center of triangular edges. The curl H equation is integrated by applying Stoke's theorem and convert it to a closed loop integral of tangential magnetic fields. This equation can be used to advance electric fields in time. To update magnetic fields, the second curl equation is used. This equation is approximated in the finite difference manner by utilizing the orthogonality property of the tessellation. The equations for the magnetic polarization case can also be derived following the similar procedure.

In order to limit the computation domain, the scatterers are enclosed with artificial outer boundaries. Continuous smooth outer boundaries, such as circles and ellipses, are chosen. The second-order time domain absorbing boundary conditions derived from the pseudo-differential operator approach is imposed at the outer boundaries. These boundary conditions are implemented with the control region approximation to determine necessary field quantities at the boundary. The results of the time domain control region approach are presented for simple scatterer geometries, such as conducting and coated cylinders and strips, by calculating both the transient and time-harmonic responses.

Far Field Pattern of a VLF Antenna Array in the Ionospheric Plasmas

The study of electromagnetic radiation from sources in the ionospheric plasmas has received much attention in the research on the satellite-borne antennas. For many years, special attention has been given to the radiation in the very low frequency (VLF) bands due to its applications in the *down-link* communication systems and local ionospheric plasma diagnostics. Efforts had been placed on the investigation on the single element radiations by many authors, both theoretically and experimentally. However, limited by its low radiation efficiency, the utility of a practically sized single VLF radiator could highly depend upon the *focusing effects* characterized by the *inflection points* on the k-surface associated with the medium. In recent years, the construction of a large space-based antenna array has been made feasible during the progress of the spacecraft technology. With a properly phased large VLF linear or planar array, a narrow beam width and consequently the high directivity can then be achieved.

In this work, the far field pattern of a two dimensional VLF phased array located in the ionosphere is analytically examined.[21] We present several designs of phasing scheme under which the planar array is allowed to be rotated 360° physically with respect to an axis perpendicular to the plane of the array, and the main beam is kept in the same direction as that of the geomagnetic field line at the same time. The tradeoffs between the beamwidth, the operating frequency and the size of the array are discussed. The performances of the array of different design are also compared.

The applicability of the principle of pattern multiplication is also discussed. More specifically, when there are more than one stationary phase point exist during the process of evaluating the radiation integral, or, in an other word, when the k-surface of the medium possesses inflection points, the simple multiplication of the array factor and the element pattern will not result in the correct overall far field pattern of the array. For these cases, we take into account the type (e.g., electric dipole or magnetic dipole) and the orientation (e.g., parallel or perpendicular to the geomagnetic field line) of the radiating elements as well as the array configuration in calculating the far field pattern.

Radar Cross Section Prediction of Slots in Ground Planes

The scattering of electromagnetic waves from a two-dimensional slot in a a ground plane is solved using the method of moments.[22] The contribution of the surface features, such as slots and other discontinuities, to the total radar cross section (RCS) of objects is of practical interest in the RCS community. In formulating the integral equation for the transverse magnetic field case, the problem is separated into two regions. The region below the ground plane is treated as a parallel plate waveguide. In the region above the ground plane, the slot aperture is replaced with a magnetic surface current sheet and the ground plane is removed by adding the necessary image sources. The integral equation for the magnetic surface current sheet over the slot aperture is then obtained by matching the boundary conditions over the aperture. The resulting integral equation is then solved with the method of moments. Galerkin's method is used with the pulse basis function.

The solution is then extended to the cases where the slot is terminated and/or when the slot is filled with dielectric/magnetic materials. This is a straightforward extension since the waveguide modes for the parallel plate waveguide filled with materials can be easily expressed. The scattering characteristics of surface slots are illustrated by plotting the two-dimensional RCS as functions of incidence angle and frequency. The effects of filling the slots with conducting materials are presented. Other techniques useful in studying electromagnetic wave scattering characteristic of various two-dimensional surface features are also discussed.

Faraday Polarization Fluctuations in Transionospheric Polarimetric VHF Waves

As radio waves propagate through the ionosphere, wave scattering can occur as a result of ionospheric density irregularities which give rise to fluctuations in Farady rotation angles, known as Farady Polarization Fluctuations (FPF). FPF have been observed with low-orbit satellite beacon signals transmitted at frequencies 20, 40, and 54 MHz, and also with geostationary satellite signals at 136 MHz. It has been shown experimentally that when the linearly polarized waves, decomposed into two characteristic wave modes, were measured separately after transionospheric propagation, there was a loss of correlation between the two characteristic wave modes. Diffractive scattering of radio waves by ionospheric density irregularities has been suggested to be responsible for this phenomenon. The density irregularities have been considered to be isotropic and modeled by correlation functions having the same correlation length in all directions. Ionospheric plasma, however, is magnetized by the geomagnetic field and ionospheric density irregularities tend to elongate along the magnetic field. The elongation results in the formation of field-aligned rod-like irregularities. Sheet-like irregularities have also been predicted theoretically and measured recently. In this work, the geomagnetized ionosphere with density irregularities is modelled as a gyrotropic random medium and the effects of both rod-like and sheet-like random density irregularities in causing FPF of VHF radio signals are studied by means of three-dimensional correlation functions.[23]

The model is used to explain the intense FPF observed in polarimetric records of 136-MHz satellite signals received at Ascension Island in 1980 and 1981. The VHF signals were transmitted from the geostationary satellite SIRIO and propagated through the ionosphere near the Appleton equatorial anomaly crest where the ambient plasma density was high especially during the 1980 solar-maximum period. For rod-like irregularities, the theoretical results predict the field-aligned enhancement of FPF. The enhancement is shown to be stronger for longer rod-like irregularities. Furthermore, the results also demonstrate an inverse relation between the strength of FPF and the wave frequency. For sheet-like irregularities, the results also exhibit the field-aligned enhancement of FPF and the decreasing FPF strength with increasing propagation angle. The difference, however, is that the FPF strength due to the sheet-like irregularities have slower decreasing rates at small propagation and have larger values at large propagation angle than the FPF due to the rod-like irregularities. For VHF waves, the RMS FPF due to the rod-like and sheet-like irregularities are quite distinctive. This suggests that the RMS FPF data with multi frequencies and multi propagation angles can be used to infer the size and shape of ionospheric irregularities.

A New Finite-Difference Time-Domain Grid Model for Microstrip Problems in Anisotropic Media

The Finite-Difference Time-Domain (FD-TD) method was first introduced by Yee who discretized Maxwell's time dependent curl equations with second-order accurate central-difference approximations in both the space and time derivatives. Since then, it has been applied extensively to scattering and wave absorption problems. Application of the FD-TD method to microstrip problems, in which frequency-domain approaches have dominated, has so far attracted little attention until recently. It has been used to obtain frequency characteristics of microstrip cavities. Then, it was further extended to the analyses of open microstrip line and microstrip discontinuity problems where absorbing boundary conditions are needed for the simulation of the unbounded domain. However, only isotropic or simple anisotropic media were considered.

In this work, a new FD-TD grid model is used to solve microstrip problems in anisotropic media having tilted optical axes expressed by permittivity or permeability tensor with off-diagonal elements.[24] This grid model is indeed a superposition of two conventional grids with some displacement which depends on the optical axes of anisotropy. Implementations of different boundary conditions are discussed. Using this model, the frequency-dependent characteristics of microstrip lines are investigated. The microstrips are assumed to be placed on top of anisotropic substrates with tilted optical axes. The case with superstrate is also investigated.

In the finite difference computation, the open-end termination is simulated by using the open-circuit, short-circuit technique. The source plane is implemented by using a magnetic wall with a Gaussian pulse excited on the surface under the strip. Because of the symmetry of the problem, the region under consideration can be reduced by half, using a magnetic-wall at the center plane.

The fields at different positions are first calculated. Then the Fourier Transform is taken to give the field spectra from which the voltage and current can also be obtained. Using these data, the effective permittivity and the characteristic impedance can be determined. The frequency characteristics of microstrip lines in anisotropic media obtained by this method are compared with the published results.

Transient Analysis of Capacitively Loaded VLSI Off-Chip Interconnections

The transient propagation characteristics of VLSI interconnects with discrete capacitive loads at various locations is analyzed based on a hybrid transmission lines-lumped element circuit model. Exact expressions of the Laplace transform of unit step responses are first obtained through the ABCD matrix formulation. We then apply the equivalent dominant pole approximation to the transfer function with the propagation delays factored out. The approximated transfer function can be inverted in closed form and quickly evaluated. These results provide efficient ways of finding approximately the effects on delays and rise time brought by VLSI off-chip interconnects.

Because of the dramatic increase in device densities on microelectronic chips, the propagation delay for off-chip interconnects has become the limiting factor to the speed of VLSI packages. Typical scales of these interconnects will be comparable or larger to the characteristic wavelength of high frequency components of the signal. Therefore, to calculate the delays caused by these interconnects properly, a hybrid circuit model containing transmission line sections as well as lumped elements must be used in place of the all-lumped element. Most circuit simulation packages are nevertheless based on the latter and have to resort to subsection approximation when dealing with transmission lines. This scheme will undoubtedly lead to lengthy computation, which is not desirable when a quick, heuristic estimate of bounds are needed for the initial phase of the design cycle.

Two approaches have been developed for obtaining the approximate transient response without lengthy simulation. The first kind of solution techniques emphasize the calculation of bounds to voltage responses from the differential equations either by direct integration or by using the optimal control theory. On the other hand, the second kind of techniques analyze the properties of Laplace transform domain solution. Thus far, their applications are limited to all lumped-element and distributed RC networks, which can only take care of on-chip interconnects. In this work, we shall take the second approach by incorporating transmission line elements for off-chip delay estimation.

Our configuration includes a series of transmission line sections with arbitrary discrete capacitances and resistances loaded at junctions.[25] The ABCD matrix formulation is used to obtain the Laplace transform of the unit step response. We express the latter in the form of $\exp(-sT)/Q(s)$, where $Q(s) = A_0(s) + A_1(s)\exp(s\tau_1) + A_2(s)\exp(s\tau_2) + \cdots$ with all $\{A_i(s)\}$ being rational functions in s. The factor $\{\exp(-sT)\}$ is identified with direct transmission delay over the total length of the line. For the rest part $(1/Q(s))$, we proceed to apply the equivalent dominant pole approximation technique. Either a single negative real pole or second-order complex conjugate pair will be chosen for approximation depending upon the property of lumped loads at junctions as well as the source impedances. A phase-correction factor $\exp(-sT_m)$ is introduced to make up for the discrepancies caused by our low-order approximation. The first-order and second order approximations enable us to obtain closed-form solution to the transient response. Comparison of the approximated responses with those obtained from brute-force numerical Laplace inversion shows very good match when the propagation delay of an average transmission line section is less than half the product of junction load capacitance and transmission line characteristic impedance. The accuracy of this method is discussed in detail with some examples of lossless transmission line networks in which lumped capacitors are loaded at regular intervals.

Absorbing Boundary Conditions on Circular and Elliptic Boundaries

The finite element and finite difference methods are increasingly popular in the computational electromagnetics community. A major issue in applying the methods to electromagnetic wave scattering problems is to confine the computation domain, which is accomplished by selecting an outer boundary and imposing absorbing boundary conditions to simulate the free space. The absorbing boundary conditions used may be exact or approximate conditions. In general, exact absorbing boundary conditions are computationally inefficient and approximate absorbing boundary conditions have been used widely, which are shown to be efficient and with sufficient accuracy. Two distinct approximate absorbing boundary conditions have been used in the past. For the circular outer boundary, Engquist and Majda obtained the absorbing boundary conditions via the pseudo-differential operator approach. Bayliss and Turkel derived a circular boundary operator by assuming the Wilcox type expansion for the scattered fields and developing a series operators to eliminate the inverse power series. The most widely used operator is the second-order operator and it has been shown to have higher absorbability than the corresponding Engquist and Majda condition.

In this work, a pseudo-differential operator approach is employed to derive absorbing boundary conditions for both circular and elliptic outer boundaries.[26] The pseudo-differential operator approach employed by Engquist and Majda is modified to derive improved absorbing boundary conditions. In the case of circular outer boundary, the modified pseudo-differential operator approach leads to a condition equivalent to that of Bayliss and Turkel's second-order condition. The pseudo-differential operator approach is then extended to the elliptic boundary case. For scattering by elongated scatterers, the elliptic outer boundary can be used to reduce the computational domain. The elliptic coordinate system is employed which has two dimensionless parameters. In the circular boundary case, the normal parameter has the dimension of length and the decay term comes from the first order derivative. Thus, a new normal parameter, which is the arc length along a constant tangential parameter, is defined in the elliptic coordinate. The Helmholtz equation is then converted to include first-order derivative of the new normal parameter. The absorbing boundary conditions for the elliptic boundary is obtained following a similar procedure as in the circular boundary case. It is shown that in the limit of vanishing interfocal distance, the boundary conditions for the elliptic boundary reduces to the results of the circular boundary case.

The effectiveness of the second-order absorbing boundary condition on the elliptic outer boundary is illustrated by calculating scattered fields from various objects. The results obtained with elliptic boundaries are compared with those obtained using circular boundaries. The advantage of using the elliptic outer boundary in reducing the computational domain is illustrated by calculating scattering from elongated objects such as strips. Furthermore, the choices for the ellipticity of the outer boundary for a given scatterer dimension are discussed.

Principles of VLF Antenna Array Design in the Magnetized Plasmas

The study of electromagnetic radiation from sources in the ionospheric plasmas has received much attention in the research on the satellite-borne antennas. For many years, special attention has been given to the radiation in the very low frequency (VLF) band due to its applications in the down-link communication systems. Intensive efforts had been placed on the investigation on the single element radiations by many authors, both theoretically and experimentally. However, limited by its low radiation efficiency, the utility of a practically sized single VLF radiator could highly depend upon the focusing effects characterized by the inflection points on the k-surface associated with the medium. In recent years, the construction of a large space-based antenna array has been made feasible during the progress of the spacecraft technology. With a properly phased large VLF linear or planar array, a narrow beam width and consequently the high directivity can then be achieved.

In this work, we study the far field pattern of a VLF phased array located in a magnetized plasma.[33] We discuss the general principles of antenna array design in the anisotropic media. Special attention is drawn to the two-dimension planar array allowed to rotate with respect to an axis perpendicular to the plane of the array, and the main beam of which is kept in the same direction as that of the geomagnetic field line during the rotation. We also discuss the applicability of the principle of pattern multiplication as well as the effects of different types of radiating elements for different k-surface geometries.

Transient Electromagnetic Wave Propagation on Vias of Multilayer Integrated Circuit Packages

In order to provide shorter interconnects between chips, modern multilayer integrated circuit packages for high-performance mainframe computers employ not only conventional striplines but vertical transmission lines or so-called vias as well. Because vias may be of comparable length with the striplines, the study of transient electromagnetic wave propagation on the former is equally indispensible to the understanding of how fast the multilayer integrated circuits can operate.

In this work, idealized circuit packages consisting of circular vias going through circular holes in the ground planes that separate different layers of equal thickness are considered.[27] When only one via is present, we show that by treating the layer between two ground planes as a radial waveguide driven by a coaxial feed and making use of symmetry the equivalent network parameters for each layer can be obtained. The multiple layers constitute a periodic structure and presents little difficulty in computing the total transmission matrix. We also study an infinite array of vias and holes with equal spacing along two perpendicular directions. By virtue of the image theory, the problem is reduced to a coaxial transmission line with square outer wall and periodic circular diaphragm discontinuities. Both variational approaches as well as the integral equation method can be applied to the calculation of the characteristic impedance, the junction impedance, and the effective propagation constant. The transient response is then obtained by performing the fast Fourier transform on the frequency domain response or by direct Laplace inversion when the dispersion of junction capacitances is negligible. Our numerical results based on the dimensions of an actual package show that the degree of reflection and signal distortion becomes intolerable when the input rise time is shorter than 500 ps.

Input Impedance of Microstrip Antennas Using the FD-TD Method

Analysis of microstrip antenna problems has traditionally employed the dyadic Green's function and method of moments approach. This approach is very desirable since the domain of the problem may be infinite and the problem can be formulated without significant approximations. Difficulties with this method are that the integral equations resulting from the formulation are numerically intensive to solve, in addition, the proper modeling of the feed greatly increases the difficulty of the problem formulation and solution.

The three dimensional finite difference time domain (FD-TD) method is a full-wave method of analysis that eliminates many of these difficulties by solving the Maxwell curl equations directly in the time domain on a discrete mesh. Perfect conductors are treated by zeroing the tangential electric field on conducting surfaces, therefore various feed structures are easily modeled. Layered lossy dielectrics are also easily modeled by discretizing the permittivity and conductivity used in the electric field difference equations. Voltage and current waveforms are calculated from the electric and magnetic fields at the input of the antenna. The input impedance as a function of frequency is obtained from the Fourier transforms of the voltage and current waveforms. An important aspect of the FD-TD method, that is examined as it applies to microstrip antenna modeling, is the treatment of the outer boundaries using either the first-order (normal incidence) or second-order (oblique incidence) absorbing boundary conditions.

The FD-TD method is used to calculate the input impedance of various microstrip antenna structures.[34] A coaxial probe-fed microstrip antenna, a line-fed microstrip antenna, and an aperture coupled microstrip antenna are analyzed. The calculated input impedance results are compared with measured results. The extreme versatility of the FD-TD method is demonstrated by this analysis of microstrip patch antennas with a variety of different feed structures.

Receiving and Transmitting Characteristics of an Infinite Array of Probe-Fed Stacked Circular Microstrip Antennas

As microstrip antennas of stacked configurations have found increased use in recent years due to their broader bandwidth as compared with their single patch counterparts. predicting their radiating characteristics has become increasingly important. While the study of microstrip antennas of conventional single patch both as isolated elements and in infinite planar arrays has been abundant, the study of scattering, transmitting, and receiving characteristics of microstrip antennas of stacked geometries is extremely limited. Recently, a rigorous analysis of a single element consisting of two circular disks in a stacked configuration driven by a coaxial probe has been performed.

Investigated here are the receiving, scattering, and transmitting properties of an infinite planar array of stacked circular microstrip antennas with an offset coaxial probe.[35] The receiving properties of the antenna are obtained by superposition, decomposing the problem into the scattering case where the antenna is short-circuited and the transmitting case. For both the scattering and transmitting problems, a rigorous analysis is performed using a dyadic Green's function formulation for an infinite array of phased sources in a layered medium. The mixed boundary value problem, confined to a unit cell of the structure, is reduced to a set of coupled vector integral equations using the vector Hankel transform and solved by employing Galerkin's method in the spectral domain. The unknown disk currents are expanded in terms of the complete set of transverse magnetic (TM) and transverse electric (TE) modes of a cylindrical cavity with magnetic side walls. An additional term in the current expansion is taken to account for the singular nature of the current on the disk in the vicinity of the probe and to ensure continuity of the current at the junction. By solving the above two problems, determined are the scattered current of the short circuited antenna when illuminated by an incident uniform plane wave and the input impedance. Scanning performance, input impedance, received power, and cross polarization levels are obtained for different incident angles, polarizations, and separation between elements.

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